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Why Were the Soil Tunnels of Cu Chi and Iron Triangle in Vietnam So Resilient?

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Abstract

At the peak of the Vietnam War, the network of tunnels in the Iron Triangle and Cu Chi linked Viet Cong (VC) support bases over a distance of some 250 km, from the Ho Chi Minh Trail and Cambodian border to the outskirts Saigon. In the early 1960s, the United States escalated its military presence in Vietnam in support of a non-Communist regime in South Vietnam. The North Vietnamese and VC troops gradually expanded the tunnels. Tunnels frequently were dug by hand in Old Alluvium terraces, and only a short distance at a time. Four major efforts were made by the US Military to locate and destroy these tunnels. These included Operation Crimp, a search and destroy mission which began in 1966 and a geological and soil survey approach was used to detect VC tunnels. Later in 1967, General William Westmoreland tried launching a larger assault on Cu Chi and the Iron Triangle areas. The operation called Operation Cedar Falls was an expanded version of Operation Crimp. Finally in 1969, B-52s started carpet bombing the Cu Chi and Iron Triangle areas and destroyed many of the tunnels. However, not before the tunnels had proven very effective in 1960s at hiding and protecting the VC during US occupation of the area. The nature and properties of the Old Alluvium soils were key to the soil tunnels being so resilient. Soils located in Old Alluvium terraces had high levels of clay and iron. Iron (Fe) leached from the upper soil layers (0 to 1.5 m) and accumulated in the lower layers (1.5 to 20 m) and became a cement-like binding agent. When dried the soil layers took on properties close to concrete, and were resistant to ever becoming soft and moist again especially around the aerated tunnel walls. The tunnels were dug in the monsoon season when the upper layers of soil were soft and moist but not in dry season. The soils were highly stable without any lining or support. After drying out, the soil materials surrounding the tunnel turned into concrete like material that could withstand adjacent explosive blasts.

Keywords

Resilient Soils, Soil Tunnels, Ultisols, Fe, Old Alluvium

1. Introduction

The soils of Vietnam (Figure 1) formed from the humid topical climate and diverse geography of Southeast Asia have shaped Vietnam's ethno-cultural relations, its turbulent history and economy, and ultimately its borders as it became a nation. Vietnam is known world-wide for the agricultural productivity of its soils and climate: rice, coffee, rubber, tea, exotic tropical fruits and vegetables.

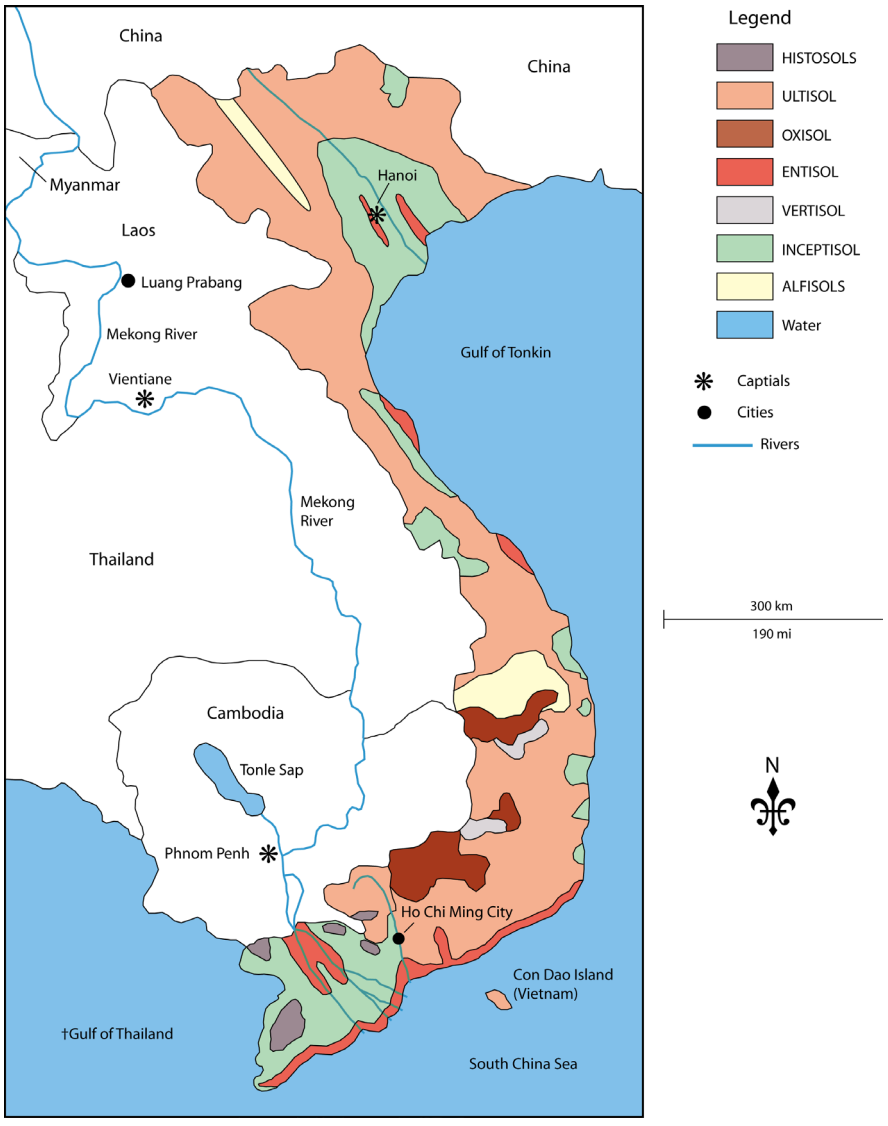

Figure 1. A soil map of Vietnam. Adapted from FAO/UNESCO Preliminary Definitions, Legend and Correlation Table for the Soil Map of the World. World Soil Resources Report No. 12; Rome: 1964. Adapted from [2] Moormann. F. R. The Soils of the Republic of Vietnam. Saigon: Ministry of Agriculture, 1961.

Less well known is how its Old Alluvium soils provided the raw material for tunnel building used for housing and guerilla warfare against colonial occupiers for centuries. The grey podzolic and low-humic gley soils mapped by Dudal and Moormann in the soil surveys of southern Vietnam and the lower Mekong region were formed in the river terraces of the ancient Mekong River [1] [2] [3]. The primary objective of this paper is to determine how the Cu Chi and Iron Triangle tunnels systems survived over two years of US bombing and still allow the Viet Cong to invade South Vietnam during the 1968 Tet offensive. In this paper we examine the unique properties of Old Alluvium soils and conditions that made them particularly well suited for the tunnels built near Cu Chi and the Iron Triangle north of Ho Chi Minh City (formerly Saigon) along the Saigon River in southern Vietnam (**Figure 2**) and the role these tunnels played in protecting the North Vietnam forces when they invaded Saigon and South Vietnam in 1968.

1.1. Soils of Vietnam

The monsoons and cyclonic storms of Southeast Asia govern the precipitation patterns and hydrological regime of its rivers, which in turn affect the weathering of soils [4] and their different physical-chemical compositions. The soils of Vietnam were formed by high tropical temperatures, alternating seasons of very high precipitation and very dry periods, sedimentation during river flooding, and intrusions of the South China Sea. Fertile river delta and alluvial soils (**Figure 1**) have supported a concentrated and diverse population for centuries, made possible by extensive rice cultivation and fishing. The Mekong Delta soils are young—Entisols, Inceptisols and Histosols derived from continuous fluvial deposits from the Mekong River and its tributaries flowing out of Tibet and south carrying sediments from the lands of Laos, Thailand, and Cambodia into Vietnam and the South China Sea (**Figure 1**). Old Alluvium soils (Ultisols and Oxisols) found about 10 m above the Mekong Delta are floodplain deposits

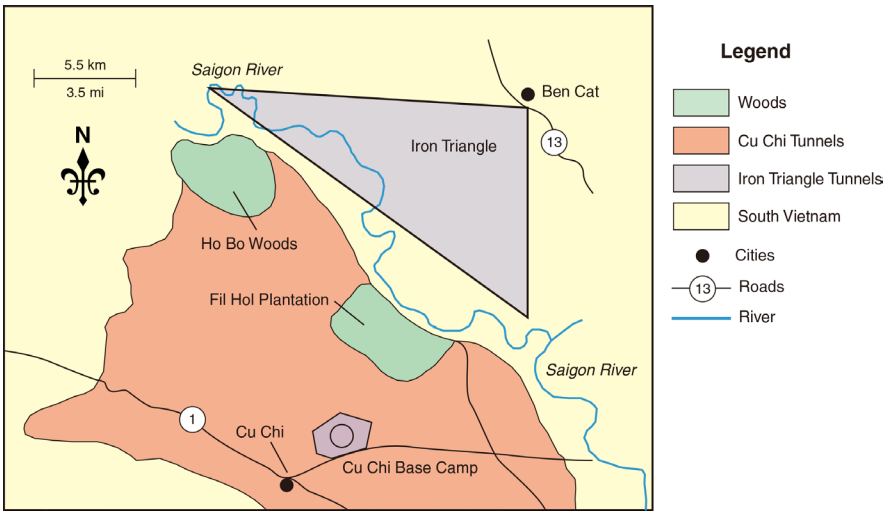

Figure 2. The Cu Chi and Iron Triangle tunnel areas and the Cu Chi US Military base camp located near the Saigon River about 80 km northwest of Saigon (Ho Chi Minh City), Vietnam.

formed when the South China Sea covered southeast Vietnam millions of years ago [5]. It is these Old Alluvium soils, in southeast Vietnam, that are of interest to this paper. Burns, a civilian geologist from the United States (US) assigned to determine the soil properties of the tunnels and predict tunnel locations in the mid-1966, identified the Old Alluvium soils as a common factor in their location. Soil materials in these old floodplain terraces were mostly clays with silt and fine sand mapped as grey podzolic and low-humic gley soils [5].

The Old Alluvium terraces of sedimentary sands produced podzols and acrisols though clay leaching [6]. Podzols (FAO/Unesco classification) are highly acidic (~4.5) and have a subsurface horizon that is light grey and strongly bleached which grades into a dark brown-reddish illuvial horizon which includes iron oxides [6]. Acrisols are podzolic soils called "lateritic" because their clay has a low silica: alumina ratio. Acrisols have a base saturation level of under 50% and generally a low base exchange capacity of 16 - 24 M-equiv/100g clay. Kaolinite is the dominant clay with little or no montmorillonite or illite. When the sand fraction of the eluvial horizon is almost white these soils are termed grey podzolic. According to Dudal *et al.* [6], some grey podzolics are ferric luvisols (rather than ferric acrisols) because their base saturation level exceeds 50%. Grey podzolic soils are dominant on the Old Alluvium terraces of the Mekong River basin.

The processes by which the iron content leaches from upper podzolic soil layers and accumulates in lower layers is described by Dudal *et al.* ([6], p. 160), "the wet season and high temperatures bring about the eluviation of all basic components-calcium, potassium, magnesium and sodium oxides-and high acidity." Simultaneously, advanced hydrolysis occurs which can lead to degradation of clays and the release of silica, iron oxides and alumina (ferralsols). They further explain that part of the iron content is converted during the wet season into a reduced form and migrates to other layers in the soil; while the dry season temporarily stops the migration and fixes the iron oxide. This process, "ferrugination," is the result of 1000s of years of weathering and is evidenced in soils with a reddish color or a hard pan of iron. When these lateritic soils are fully air-dried, they take on concrete-like properties and are resistant to becoming soft and moist again [5]. It is this characteristic that makes these soils well suited to tunnel construction. Tunnels have been found wherever grey podzolic soil is mapped in woodlands or cultivated fields at higher elevations. Low-humic gley soils of the Old Alluvium are hydromorphic characterized by gleying throughout the profile or by evidence of prolonged saturation in the upper 50 cm layer. Where the water table was shallow, low-humic gley soils are not suitable for tunnel construction; but can be found at higher elevations [5].

1.2. Historical Use of Tunnels for Housing and in Warfare

The French were not the first to colonize the lands now known as Vietnam. Long before the ethnic Viet moved south from the Red River basin of northern Vietnam, the Jarai, Cham, Khumers, Tai and over fifty other ethnic groups lived

along the central coast, throughout the Mekong Delta, and in the highlands adjacent to the Red River lowlands [7]. The cradle of Vietnamese civilization traces its heritage to the Red River Delta of northern Vietnam. Adjacent to southern China, this region was settled by people arriving by sea and overland from China [7]. The name Viet Nam is Chinese; with the word "Viet" describing the peoples as "those from beyond" China and joined with the word "nan" meaning south. As the Chinese empire attempted to control these southern lands, they also transferred agricultural practices, dikes and canal building, social customs, culture, uniform language and administrative rules as well as patterns of trade into Indian Ocean markets. It is likely the Viet people acquired tunnel building knowledge from the Chinese and carried it forward into Vietnamese culture [7].

During the 16th century, millions of Chinese were living in caves and tunnel systems in China. Most of these sites were well-drained with a low water table. Tunnels and caves dug in loess soils (Mollisols or prairie soils) were easy to dig by hand, but they lacked the iron oxide cements that make soil more stable. In the 16th century one of the deadliest sequence of earthquakes in Chinese history occurred; and many of these tunnels collapsed killing approximately 830,000 people [7].

The Viets began building their own empire and expanded southward as Chinese colonialism loosened its hold on the Red River valley. As part of nation building, Viet colonialism was "marked by violent confrontations with indigenous peoples whom they conquered" ([7], p. 9). From the 18th through 20th centuries, Viet and non-Viet people in the region engaged in many rounds of civil war punctuated by colonial occupations by the Russians, French, and Americans. Prior knowledge of soils best suited for tunnel construction could explain the speed and skill with which the Viet Cong of North Vietnam employed tunneling in times of occupation and war.

Military use of tunnel networks under the jungle terrain of South Vietnam started during World War II (late 1930s and early 1940s) when Viet Minh national guerillas fought the Japanese prior to the Japanese overthrow in 1945 of the French who claimed Vietnam as colonial territory. Tunnels extending short distances were hand dug during the rainy season when the soil was moist for small local units to use. In the early 1960s, the US, concerned about the aggressive expansion of communism in Vietnam, increased its military presence to support the Republic of Vietnam, the non-Communist regime in South Vietnam. North Vietnamese and Viet Cong troops expanded the tunnels and used them in conjunction with their guerrilla warfare tactics. The network of tunnels in the Iron Triangle and Cu Chi (**Figure 2**) connected Viet Cong support bases running from the Ho Chi Minh Trail (**Figure 3**) and Cambodian border to the edge of Saigon, a distance about 250 km.

As the United States increased their aerial bombing, North Vietnamese and Viet Cong soldiers used the tunnels to survive and conduct guerrilla warfare against the well-equipped American enemy. People living in these areas spent much of their life underground. The tunnels of Cu Chi grew from temporary

Figure 3. The Ho Chi Minh Trail through Vietnam, Laos and Cambodia was a main route for moving food, military equipment and North Vietnamese Communist soldiers (Viet Cong) from North Vietnam into the Cu Chi and Iron Triangle region of South Vietnam.

quarters for a few soldiers to encompass entire underground villages of soldiers with kitchens, living quarters, hospitals, ordinance factories, and bomb shelters (Figure 4). Some tunnels had large underground theaters and music halls to provide entertainment for the peasant soldiers. The tunnels proved very effective

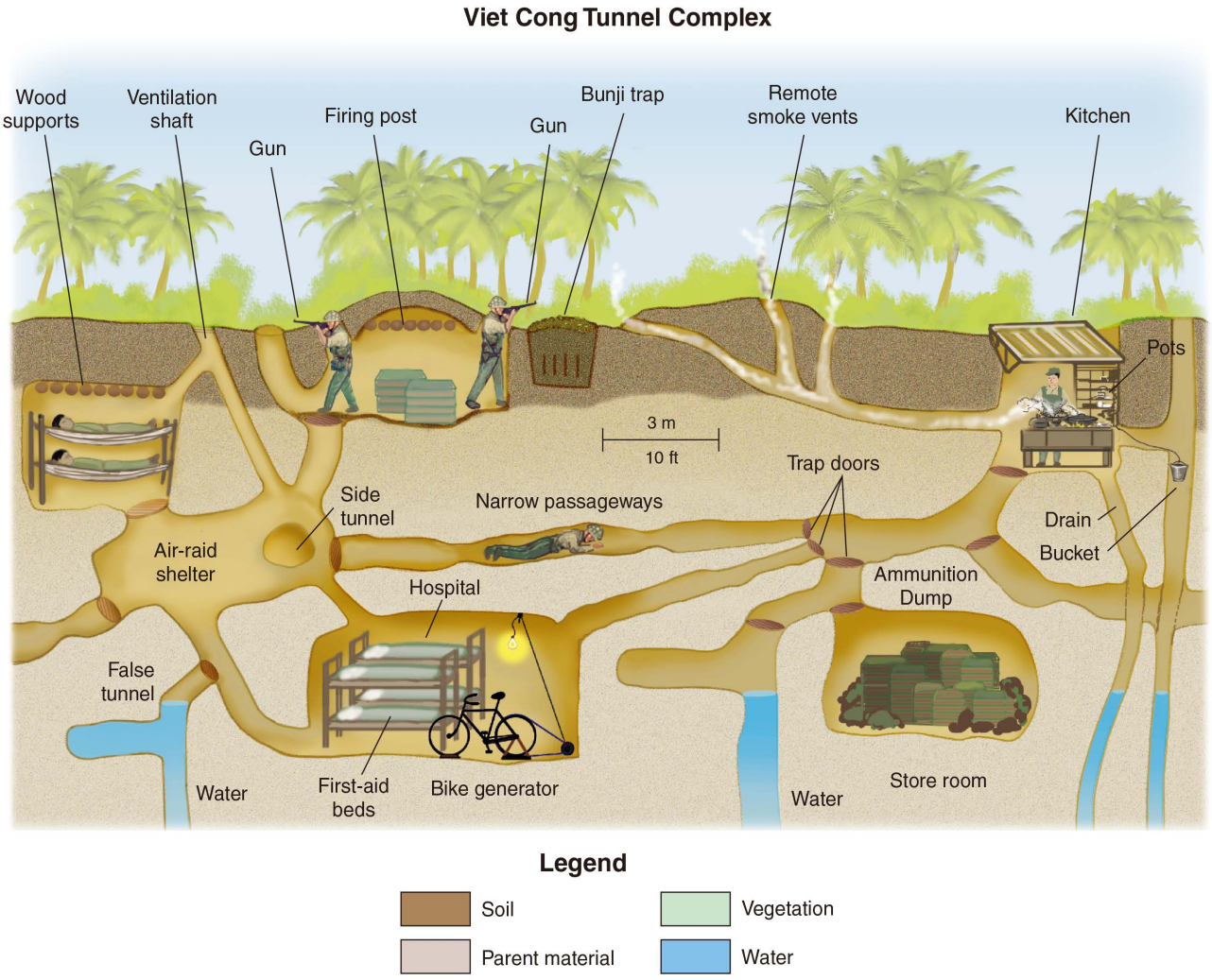

Figure 4. This diagram illustrates a multi-level Viet Cong tunnel complex used for living quarters and fighting. Based on displays at Vietnam Memorial at Ben Dinh near Saigon.

in hiding and protecting the VC in 1960s at the height of the US Vietnam occupation. The soil tunnels at Cu Chi and the Iron Triangle (**Figure 2**) were so extraordinarily stable and resilient that they withstood three years of US military aerial bombing. The reason appears to be the nature and properties of the Old Alluvium soils.

2. US Armed Forces' Methods Used and Operations Conducted to Locate and Destroy the Cu Chi and Iron Triangle Tunnels

Tunnel construction and use were fragmented and localized prior to the Vietnam War. As the Americans replaced the French as the Democratic Republic of Vietnam's enemy no. 1 in the Indochina war, the US moved from rhetoric to military occupation of southern Vietnam in support of the non-communist Republic of Vietnam regime [7]. There was no formal master plan for the development of interconnecting tunnels; the tunnel infrastructure evolved as the war

accelerated. Expansion of tunnels into complexes that supported VC guerilla supply lines and munitions became an effective strategy to combat advanced US weapons and technologies. The tunnels were an Achilles heel for the US and their military used four approaches to locate and destroy the Cu Chi and Iron Triangle tunnels (Figure 2) from 1966 to 1969. These were 1) Operation Crimp, a search and destroy mission; 2) geologic and soil survey mapping to locate the areas in South Vietnam most likely to have tunnels; 3) Operation Cedar, an expanded search and destroy mission and finally 3) aerial carpet bombing of the entire Cu Chi and Iron Triangle area.

3. Results and Discussion

3.1. Tunnels of Cu Chi and Iron Triangle

The Cu Chi and Iron Triangle tunnel systems are northwest of Ho Chi Minh City (Saigon) (Figure 2) and both tunnel systems were used by Viet Cong to get from Ho Chi Minh Trail at the Vietnam-Cambodian border to Saigon and South Vietnam. These adjacent tunnel systems served as a stronghold of VC during Vietnam War. US soldiers and their vehicles could move easily in this upland area during the monsoon seasons (May to October) so it became a good staging area for a base camp. This was an important clue as to where tunnels could be built; but it took a while before the American forces realized the significance of the link between trafficability, tunnel construction, and soil characteristics. The reason for ease of movement of vehicles relates to the nature and properties of the soils (Ultisols and Oxisols) (Figure 1) on the Old Alluvium terraces. The Old Alluvium terraces were of strategic significance since the tunnels linked to the mainland and the Saigon River could be used by the VC to transport supplies and troops from North Vietnam into South Vietnam via the Ho Chi Minh Trail (Figure 3). The districts of Cu Chi and Iron Triangle (Figure 2) became the most bombed and defoliated areas in war history. Soils were stripped of their protective vegetative cover and became degraded, disturbed, eroded and polluted. The sediment was transported by rain events into the Saigon River, which also became degraded and polluted.

The Cu Chi and Iron Triangle tunnels were located in III Corps Tactical Zone (Figure 2). The VC moved underground in response to US artillery, aircraft, bombs, and chemical warfare. The Iron Triangle was 103 km^2 of jungle and thick undergrowth covering an intricate network of tunnels and bunkers approximately 80 km northwest of Saigon. The Cu Chi area was 40 km west of Saigon and about 51 km^2 in size. The tunnels were between 1.5 m and 20 m deep in the Old Alluvium parent material where the water table was low [5].

3.2. Water Table Limiting Factor in Tunnel Locations

Much of southern Vietnam is at sea level or slightly above with a shallow water table and high vulnerability to flooding during the monsoon season. The Mekong Delta bottomland alluvial soils (Figure 1) with its high water table could not be used for tunnels or they would have filled with water and the soil would

become more plastic when wet. The Old Alluvium terraces on higher ground were much better suited to tunneling. The depth of the water table, commonly 10 to 20 m, determined the lower limit of the useable soil and parent materials for tunnels. The upper limit for tunnel construction was at a depth 1.5 m from the surface to prevent collapse and to maintain a protective barrier from aerial bombing.

3.3. Digging of the Cu Chi and Iron Triangle Tunnels

Tunnel construction was a group effort, with two people primarily using hand methods to dig out the soil and two to three people removing the soil material from the site and transporting it to another location. The soil was often dumped into the Saigon River at night to prevent detection by US Army remote sensing technics. Soil was routinely moved to build house basements, plow furrows for growing potatoes, and construct banks and combat trenches so as to prevent tunnel construction from being discovered. Tunnel entrances were carefully engineered to conceal their presence (Figure 5). Boards 1 cm thick and 2 to 3 cm wide were arranged in two frames, one horizontal and one vertical over the entrance. The frames, covered with wax and sponge rubber, simulated natural ground when someone stepped on the entrance. The trap door sides were beveled at an angle so the boards could withstand the weight of heavy military vehicles and not collapse and reveal the opening (Figure 6).

Many of the tunnels had camouflaged trap doors covered with soil and dust (Figure 5). When a door led directly to the outside ground surface, foliage, branches, and soil were placed to conceal the door. These materials were replaced every three days to keep their natural look. The entrances were in elevated and dry areas with good ventilation to resist flooding, fires and chemical

Figure 5. Tunnel entrances had a trap door covered with soil, leaves, and branches to conceal the entrance. The tunnel complex would have many difference entrances in a variety of locations to enable quick exit in case of discovery.

Figure 6. Tunnels were constructed in Old Alluvium lateritic soils where weathered iron oxides made the soils hard like concrete. The soil lining of the tunnel and steps which led up from the tunnels to the entrance were so resilient it was hard for the enemy to destroy the tunnels. This tunnel entrance was preserved as part of the Vietnam War memorial park.

warfare (e.g. herbicides 2,4,5-T and 2, 4-D, Agent Orange). Occasionally entrances were placed in pig pens where US soldiers seldom looked [5]. Tunnel excavation was not horizontal or vertical but in zig-zag angles between 60 and 120 degrees to help deflect explosive blasts (hand grenades) if found and invaded and to prevent linear small arms lines-of fire. Communication passages were between 0.8 and 1.2 m and a height of 0.8 to 1.8 m (**Figure 4**). Tunnel dimensions were uniform, well-constructed and building standards were adhered to strictly. Large framed and heavy soldiers, like many Americans and Australians, could not get through the small, narrow tunnels.

3.4. Complexes

Tunnels had one to four levels with secret trap doors separating them. Tunnel complexes included storage depots, conference rooms, hospitals, ordinance factories, kitchens, troop headquarters, sleeping and dining areas, and other rooms needed for a functioning army (**Figure 4**). Some passage ways were flooded to make it difficult to get to the next connected chamber. A water bend every 100 m controlled tunnel flooding and prevented tear gas or CS (2-chlorobenzalmalononitrile) riot gas from engulfing the entire tunnel complex [5]. Ventilation holes were essential to ensure fresh air and to prevent rainwater from flooding into the tunnels. These holes running obliquely from the soil surface to the first level often had an eastern orientation to let light in or pointed into the prevailing wind to improve tunnel air circulation.

Entrances were constructed in a triangular pattern, 40 to 50 m apart, to support each other. Multiple openings allowed VC to take alternative escape routes out of the tunnel complex so as to not be trapped. Tunnels openings facilitated guerilla tactics by allowing scouts to monitor the enemy and use surprise sniper

attacks—shooting and then disappearing. After intensive bombing in the Iron Triangle (Figure 2) during the Vietnam War, new conical A-shaped tunnels were built to resist the deep penetration of artillery and bomb blasts. However, this new design became an echo chamber that amplified the sound of B-52 airplanes as they approached with their load of bombs and dropped them on the tunnel area. It was not known until after the war what a terrifying effect this echo chamber had on VC hiding in these conical shaped tunnels.

The VC observed how Americans troops acted or reacted to VC attacks. This helped them to create new attack and defense tactics and specific kinds of booby traps (Figure 7) designed to mutilate, kill, and instill fear. Booby traps were responsible for 11% of all American deaths and 27% of all wounded during Vietnam War (1960s) [5]. Along with inventive booby traps, the VC were quite skilled in repurposing recovered American munitions. When they ran low on explosives, the unexploded US ordinance and bombs (Figure 8) were retrieved and reused.

3.5. Life in the Tunnels

The dark, narrow, and dangerous tunnels were called "Black Echo" by American soldiers. Life in the tunnels was not easy for the VC despite their small size and knowledge of how they were constructed. The tunnels were engineered to provide air for breathing, rooms for food storage, and portable water, but quality and quantity were in short supply. The VC shared space with ants, spiders, scorpions, poisonous centipedes and other insects and underground animals. The tunnels were a refuge in the daytime where soldiers could sleep, eat, clean-up and prepare their guns and plan attacks. Once darkness arrived, they left the

Figure 7. The VC constructed many different kind of bobby traps in the jungle floor and tunnels to multilate and kill enemy soldiers. This is a clipping see-saw booby trap, one of eight on display at the Ben Dinh visitor center.

Figure 8. Rifles, hand grenades and bombs used during the Vietnam War are display at the Ben Dinh visitor center.

tunnels to tend crops, scavenge for supplies, and engage the enemy [5]. When American troops were moving on a search and destroy mission or airplanes were bombing the area, soldiers were forced to stay underground for days. The conditions in the tunnels led to continual sickness and many people had malaria, which was second only to battle wounds as cause of death. A captured VC report revealed that half of the soldiers in that unit had malaria and all of them had significant intestinal parasites. It is estimated over 45,000 Vietnamese men and women died from constructing Cu Chi and Iron Triangle tunnels and defending them during the Vietnam War.

3.6. The 25th Infantry Division at Cu Chi Base Camp

The US military soon discovered the tactical advantage that the tunnels gave to the VC. Several major search and destroy missions were launched. It was known that the tunnels in the Cu Chi and the Iron Triangle region allowed the VC to control the area and launch initiatives against the US. The 25th Infantry Division constructed their base camp in Cu Chi on an Old Alluvium terrace with intent to locate VC tunnel activity and to destroy the tunnels. The base camp was accidentally built over a tunnel network [5]. The VC used their snipe and disappear tactics within the camp; and eventually American forces found the tunnels more than 1.5 m beneath their base camp and destroyed them.

Local Vietnamese workers provided valuable support for the daily operations of the Cu Chi Base Camp. Some were VC sympathizers who gathered intelligence about the base for the North Vietnam Communists. As a result of this intelligence, the North Vietnamese army in Cu Chi district and Iron Triangle often had advance notice before US attacks [5]. This early warning system allowed the VC to make preparations and/or pull out their units until the search and destroy missions were completed. The most important of the US tunnel location and elimination operations were 1) Operation Crimp, 2) Geological and Soil Survey, 3) Operation Cedar Falls and 4) carpet bombing.

3.7. Operation Crimp

Operation Crimp turned the jungle vegetation and forest soils of Cu Chi into a pockmarked moonscape. The bombing operation began in early January, 1966, when B-52 bombers dropped 30-ton loads of high explosives onto the Cu Chi and the Iron Triangle areas. The natural iron oxide in the soil cemented tunnel linings and made them stable, resilient and hard to destroy. Then 8,000 soldiers from the US 1st Infantry Division, 173rd Airborne Brigade, and the 1st Battalion, Royal Australian Regiment searched for enemy activity. They were rather unsuccessful, since the VC troops quickly disappeared into the camouflaged underground tunnels. When US and Australian soldiers did find a tunnel, they often underestimated its size. Further, the tunnels were seldom searched because they were usually rigged with explosive booby traps or punji pits [8]. The two main strategies for cleaning out a tunnel were to toss a few grenades down the hole or flush the opening with hot tar, water or gas to force the enemy soldiers out and then "crimp" off the entrance. The tunnel design with multiple trap doors and air filtration systems made these strategies ineffective.

However, 3 Field Troop, an Australian specialist engineering unit under the command of Captain Sandy MacGregor, explored one tunnel complex for four days and found signs of VC soldiers, radio equipment, ammunition, medical supplies and food [5]. This turned deadly for one of their members who became trapped in a dead-end tunnel and could not back out. This was an important find since the Australians revealed the immense military significance of the tunnels, which was not known at the time [8]. During an International Press debriefing in Saigon regarding Operation Crimp, Captain MacGregor called his men tunnel ferrets. One journalist, an American, did not know what ferrets were and instead called them tunnel rats [9] [10]. The term tunnel rats stuck and was used by media and by the military throughout the war. Captain Sandy MacGregor was awarded a Military Cross for his leadership in the tunnel discoveries at Cu Chi.

The discovery of how extensive the tunnels were and the ineffectiveness of Operation Crimp led the US and Allied forces to realize they needed a new approach. New orders were issued which required tunnels to be properly searched every time they were discovered. This strategy required a well-trained elite group of small sized and brave volunteers willing to learn the art of tunnel warfare. They undertook this dangerous mission armed only with a flashlight and a piece of string or cord, a knife, and a gun. When these tunnel rats entered a newly discovered tunnel they inched their way forward cautiously, constantly alert for booby traps or cornered VC soldiers. Most of their skills were learned on the job despite efforts from the US Army and MACV (Military Assistance Command, Vietnam) to provide training and resources. This new approach usually left the units to train and equip themselves.

3.8. Military Occupational Specialty Code (MOS)

American tunnel rats' primary role and duties were given a military occupation-

al specialty code (MOS) to identify their specific job. At first, infantrymen were assigned to clear the tunnels. However, after many injuries and deaths, a training program for tunnel rats [11] was developed at Cu Chi Base Camp. The Australians helped provide US soldiers tunnel training. Soldiers went down into the tunnels armed only with a flashlight and pistol. The only lifeline was the telephone cord or string to pull the soldier out if something went wrong. It was especially treacherous to drop down a vertical passageway with water in it in search of a passageway to the next tunnel complex. Injuries and death often occurred when the tunnel rat encountered a VC soldier inside the tunnel [11]. VC soldiers set booby traps for US and South Vietnamese infantrymen such as planting trip wires that triggered grenades or dumping scorpions or poisonous snakes on enemy troops.

After the tunnel rats cleared a tunnel system, they would destroy it with explosives. Tunnel soil in the dry season would harden like concrete because of the iron oxide content. US Army troops learned that the desiccated clay cemented with iron oxides could withstand 16 kg charges including hand grenades and other explosives without collapsing. Most of the time, the explosives only damaged the first level of the tunnels system. The North Vietnamese soldiers simply re-dug the tunnels after the American forces left the tunnels. The US Army also attempted to flood the tunnels in order to destroy the tunnel complexes. However, in the dry season the lateritic and amorphous clay absorbed the water; and trap doors were watertight during the wet season. Although CS gas pellets could initially clear the tunnels of VC, it was only effective less than a week and the VC soon returned to use the tunnels.

3.9. Geological and Soil Survey Approach to Detection of VC Tunnels

Two geologists (Jim Burns and Perry Narten) who worked for the Research Analysis Corporation (RAC) Survey unit arrived in Saigon on October 9, 1966 [5]. They were assigned to Saigon but made short visits to Cu Chi, Bien Hoa and Tay Ninh. Although invited, they declined the chance to visit the Iron Triangle for personal safety reasons. The goals of the project, "A Systematic Approach to the Detection of VC Tunnels," involved both Australia and US personnel. Part I: Strategic and Tactical Factors was led by Major H.W. Newbigin of the Australian Army with assistance from Lieutenant J.D. Harden of the US Navy and Part II: Environmental Factors was conducted by Perry F. Narten and Jim Burns (RAC). The Army had constructed Camp Cu Chi earlier in 1966 and it became the headquarters [5] of the US 25th Infantry Division. However, at the time of construction, it was not known that the Cu Chi base camp was built over an area containing a large network of VC tunnels. When VC began to appear inside the mess hall stealing supplies and firing guns, US military leadership realized they had a big problem. Although tunnels within the camp were destroyed, tunnels outside the camp in the Cu Chi area remained a serious threat. The two geologists were urged to concentrate their efforts in this area.

The Army had information on tunnel locations and needed the two geologists to provide detailed descriptions of the geology, soils, parent materials, subsurface moisture and hydrology, and other aspects of the general environment where the tunnels were found. They were given two tasks: 1) identify any association between tunnels and specific environmental settings, which might then guide search and destroy efforts and 2) compile information on the properties of the natural materials and their changing moisture conditions, as an aid in the design of detection equipment [5].

The tunnels in III Corps Tactical Zone were found only in Old Alluvium high terraces 10 to 20 m above the Mekong Delta bottomland soils. The land use patterns (cultivated fields, hedgerows and woodlands) on air photographs made it easy to identify Old Alluvium soils. Using 1960s terminology the soils were identified and mapped as grey podzolic soils and low-humic gley soils. These soils are known today as Ultisols and Oxisols (**Figure 1**). The tunnels were found to be located anywhere in the higher grey podzolic (Oxisols) soils. However, tunnels in the low-humic gley soil (Ultisol) areas were only dug in selected sites on the higher ground. The lower areas with Entisols, Inceptisols and Histosols, such as the Mekong Delta, had high water tables and were not suitable for tunnel construction.

3.10. Geologists Characterization of Tunnel Soils

The geologists reported the tunnel soils to be mostly amorphous clay (often approaching 40%) with remainder sand and silt size particles with "lateritic" properties, meaning that the iron content acted as a cement or binding agent. When dried these soils took on properties close to concrete, and were resistant to becoming soft and moist again especially around the aerated tunnel walls. Near the ground water table were higher concentrations of iron that produced layers of laterite pebbles and rocks. These areas were very resistant to digging by hand and even using mechanized power equipment was difficult. These iron soil layers set the lower depth limit for hand digging of tunnels at between 10 and 20 m [5].

Vietnam's rainy or monsoon season (May-October) was the best time for digging tunnels. In the dry season (November to April) the soils were too hard to dig by hand. When the tunnels dried out, the adjacent soil permanently hardened and was not likely to regain moisture and softness (**Figure 6**). Trap doors in tunnels built from wood and soil (**Figure 5**) when exposed to seasons rains were often overlooked by the untrained soldier because they appeared to be natural soil.

The two geologists completed their task of identifying and characterizing the soil in which III Corps Tactical Zone tunnels were located. The soil and geologic details they provided proved useful in the design of a tunnel sensing system [5]. However, they were unable to predict exact potential locations for tunnels since the suitable soil conditions were so widespread that they could not give guidance for an effective search effort.

3.11. Operation Cedar Falls

Operation Cedar Falls was launched a year later (January 8-26, 1967) using 30,000 American troops to attack the North Vietnamese Communist stronghold of Binh Duong province north of Saigon near the Cambodian border. This area, known as the Iron Triangle, (**Figure 2**) was reported to have a network of tunnels that housed the underground headquarters of the VC Military Region IV. The Americans planned to explore the tunnel complex and destroy it. After the known civilian Vietnamese population was evacuated, all vegetation was removed and the area became a "free strike zone" [5].

Following bombing and defoliation of rice fields and jungle areas with deadly herbicides (Agent Orange), US tanks and bulldozers moved in. The dozers cleared the topsoil, exposing tunnel entrances and driving out thousands residents, VC soldiers and civilian refugees (**Figure 4**). To find the tunnels in the dry season, trees were dragged behind armored personnel carriers to create broad paths of fine-grained soil particles. Each morning the US troops would look for footprints in the dust to find the tunnel entrances where the VC came out to do their work in the dark. Once the tunnel entrance was located, the tunnel rats would explore the tunnels and take out any VC they found [8]. Operation Cedar Falls did not discover the location of the Viet Cong Military Regional IV Headquarters. The North Vietnamese troops slipped back into the Iron Triangle area a few months after the tunnels were cleared. These tunnels gave them a strategic advantage during the Tet Offensive in the 1968 assault on Saigon. Eventually US forces located the VC Area Military Headquarters in Saigon and acquired thousands of documents that included a map of major tunnels and list of collaborators.

3.12. Cu Chi Tunnels a Memorial and Tourist Destination

The tunnels of Cu Chi and Iron Triangle are an immense complex of interconnected underground tunnels located in the Cu Chi District of Ho Chi Minh City (Saigon), Vietnam (**Figure 2**). They are part of a much larger tunnel network that underlies other parts of Vietnam [11]. The Vietnamese government has preserved much of the 121 km long tunnel complex at the Cu Chi district and made it a war memorial park. Tourists can see first-hand the tunnels at Ben Dinh and Ben Duoc. They can crawl through a few of the tunnels and see command centers such as the underground conference rooms where the Tet Offensive and other campaigns were planned. A below ground conference center features a 15 millimeter black and white film that documents how the VC liberated South Vietnam from the US occupiers (**Figure 9**). Some of the tunnels have been enlarged to accommodate the larger size of Western tourists. These tunnels have low-power lights to make crawling through the passageways easier, a luxury the VC and US tunnel rats did not have. A variety of booby traps and how they work are also on display (**Figure 7**). Tourists can fire an AK-47 rifle on a firing range and taste a meal of cassava, one of the staple foods of the Vietnamese during the war.

Figure 9. The Cu Chi tunnel tourist center shows a black and white movie about the Vietnam War and has a model tunnel complex to illustrate the housing and fighting functions of the tunnels.

4. Conclusions

The soil tunnels at Cu Chi and Iron Triangle northwest of Saigon proved to be a constant source of frustration to the US military during the Vietnam War. The tunnel systems survived over two years of US bombing and still allowed the Viet Cong forces to invade South Vietnam during the 1968 Tet offensive. More than 80 million liters of herbicide was dropped on Vietnam between 1962-1971 with more than half of this load along the Ho Chi Minh Trail [7] and the Old Alluvium terraces of Cu Chi to expose the tunnels. Once the US forces stopped bombing North Vietnam in 1969 the B-52s turned to full-scale carpet bombing of the Cu Chi and Iron Triangle area (Figure 2). The resilient soil tunnels cemented with iron oxide could withstand the 1966 to 1968 US bombing onslaught and any damage was quickly repaired. However, the 1969 carpet bombing caused portions of the soil tunnels collapsed and other sections were exposed. By then the Viet Cong forces had already successfully invaded Saigon. Three years later, the US forces withdrew from the Vietnam War and the South Vietnam forces were finally defeated in 1975.

These tunnel complexes for many years effectively hid troops, equipment and supplies and provided strategic bases from which to plan surprise attacks on the Army of the Republic of Vietnam (ARVN) and US forces. They enabled the North Vietnamese Communists to become so entrenched, that by 1965 they were positioned to control where and when local battles would occur. The tunnels played a significant role in enabling the Communist VC to resist and out last an enemy with many more resources. It has been said that acts of resistance intended to force the enemy to abandon his intentions can be as powerful as aggression [8]. Although none of the US military squads or larger units ever surrendered to the North Vietnamese during the Vietnam War, the VC managed to

prevail with their guerrilla tactics and tunnel networks. US General William Westmoreland summed up the success of the North Vietnamese tunnel strategy, "No one has ever demonstrated more ability to hide his installations than the Viet Cong. They were human moles" [8]. The soil tunnels of Cu Chi and Iron Triangle allowed North Vietnamese fighters to survive in hostile South Vietnam. As a result, the war was prolonged and American casualties and costs grew, leading to their withdrawal in 1973. By 1975, the Republic of Vietnam was defeated and Vietnam became a unified country under the governance of North Vietnam.

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